NASA-AMES LASER FIELD PROGRAMS*

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The paper discusses current laser propagation and laser communication efforts supported by the NASA Ames Research Center. The laser propagation experiments will involve transmission and attenuation measurements on laser beams from a ground tracking station to corner reflectors on the Explorer 22 satellite. The laser communication experiments will involve acquisition and tracking of a ground station 5145-Å argon laser beacon by Gemini 7 astronauts, with ground reception of laser communication from the spacecraft.

Recognizing the need to obtain more experimental data on the propagation of laser radiation through the total earth atmosphere, the NASA Ames Research Center selected Electro-Optical Systems to conduct field experiments in laser propagation. The Explorer 22 satellite will be used as an orbiting reflector of laser signals from the earth. The tracking pedestals, laser transmitter, and optical receiver will also be used as a ground station on the Gemini 7 optical communication experiment. These efforts are closely integrated since so much equipment is common to both.

The prime objective of the laser propagation research effort is to study the transmission characteristics of the total atmosphere from earth to space and return. An additional objective is to perform optical experiments relating to navigation and tracking. The experiments to be performed are shown in Tables I and II. These experiments will give information on aerosol backscatter versus altitude, aerosol particle size, water-vapor distribution, corner reflector array scintillations, and laser-aided acquisition and tracking of satellites.

Because the equipment for the Laser Propagation Research Studies could economically be modified to serve as a ground station for the Gemini 7 (MSC-4) Optical Communications Experiment, and because additional propagation experiments seem possible using signals from the spacecraft transmitter, scope of Laser Propagation Research Studies was expanded to include this additional

* The paper is based on work supported by NAS 2-2962.

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effort. The principal experiments to be conducted on Gemini 7 are the basic demonstration of voice communication from a hand-held laser transmitter to a ground station and the measurement of audio frequency fluctuations in signal strength caused by atmospheric effects and pointing errors.

The accomplishment of these objectives by the NASA Ames Research Center program will have demonstrated the utility of the Explorer 22 satellite as an atmospheric research aid, will have aided the demonstration of the first laser space communication, and will have utilized the first field operation of the visible argon gas laser. Thus, in addition to direct experimental results, important advances in technology applicable to communications, tracking, guidance, and control will have occurred.

The Explorer 22 and 27 satellites were placed in orbit primarily to determine the overall profile of the earth's atmosphere. These satellites are, however, equipped with an array of quartz cube corners as retro-reflectors for propagation and tracking experiments using laser beams from earth.

The Explorer 22 is in a near-polar orbit with an inclination to the equator of 79.7°. The satellite has an apogee of 1100 km and a perigee of 939 km and is magnetically stabilized so that the corner reflectors point toward the earth when the satellite is in the northern hemisphere.

The Explorer 22 is in a high orbit, nearly circular, with relatively constant orbital parameters. The Explorer 22 satellite, equipped with a 136-MHz Minitrack beacon, is continually tracked by the NASA-Goddard Minitrack Network. The orbital track is determined by the NASA-Goddard computer. Predicted look angles for any point on earth at any time are readily available to an accuracy of several milliradians.

Because the Explorer 22 satellite is in a polar orbit, the geographic locale of a tracking site is relatively unimportant. The constancy and long life of the orbit permit reasonably accurate prediction of look angles. Thus, satellite tracking is possible independent of range facilities if the site coordinates and time are well known.

The basic ground station consists of two modified Nike-Ajax pedestals with control van. Since no major range facilities are needed, the site will be near Moffett Field, California. Some thirty sites in the mountains to the east and west of San Francisco Bay were evaluated by criteria of cloud cover, atmospheric turbulence, accessibility, logistics, sky illuminance, and available facilities. Several adequate sites were selected from this list. Since none of

these are currently government facilities, site acquisition may be an important factor. Final site arrangements await completion of the Gemini 7 program.

Look angles versus time are available from NASA-Goddard for about one week in the future. These data are accurate within several milliradians. Azimuth, elevation, and range in microseconds are encoded on the tape at one-second intervals.

In the field acquisition aid, a tape reader transfers the azimuth, elevation, range, and time data from serial to parallel form. Binary coded decimal format (BCD) is transferred to pure binary format. A digital clock advances digital angle data once per second. To drive the Nike system with these data, digital angle information is converted to synchro form by a solid-state control transformer together with 400-Hz synchro pedestal positional signals. The output of the solid-state control transformer is a 400-Hz error signal proportional to the difference in the digital angle command and the Nike pedestal angle. Range predictions may be processed by the system to generate a delayed range gate for laser ranging operations. The digital clock is driven by a precise time base generator synchronized to WWV. Figure 1 shows details of the acquisition aid system.

It is not plausible to provide tape data more often than once per second. During one second, the satellite travels approximately 3 mrad. The receiver and transmitter beamwidths are thus required to be 3 mrad or greater. If more accurate tracking is desired, to the approximate limit of the Nike system ($\approx$0.1 mrad), improved means of pedestal pointing are required.

During twilight, when the satellite is illuminated by the sun against a dark sky background, the Explorer 22 has the brightness of a 6th to 8th magnitude star. An automatic optical tracker may lock on this reflected solar energy from the satellite and provide pointing error signals to drive the Nike system. For sufficient sensitivity to track a 9th magnitude star, the optical tracker has a small instantaneous field of view ($\approx$1.2 mrad). With this small field, the tracker must be initially oriented in the vicinity of the satellite by the acquisition aid. The tracker scans its instantaneous field of view over the 3-mrad uncertainty of the acquisition aid 400 times a second. When the tracker senses the satellite and generates error signals, the tracking system operator can transfer control of the Nike system from the acquisition aid to the optical tracker.

The optical tracker utilizes an ITT-FW130 deflectable photomultiplier detector boresighted with the 40.64-cm (16-in.)-dia optical receiver. A beam splitter sends 6943-Å laser radiation to the laser detector while permitting

shorter wavelengths to reach the optical tracker detector. The tracking resolution of the electrically scanned optical tracker is better than one percent of the instantaneous field of view or < 0.01 mrad. Thus, tracking accuracy will be limited by the Nike pedestals to approximately 0.1 to 0.2 mrad. Both satellite acquisition and tracking are automated functions requiring no operator at the Nike pedestal. All tracking functions are controlled from the control van. Figure 2 shows details of the optical tracker.

Explorer 22 atmospheric experiments will define atmospheric effects on laser propagation and will probe atmospheric composition. Explorer 22 tracking experiments will involve satellite ranging, laser-aided acquisition, and laser-aided tracking.

With the Ionized Argon Laser on one Nike pedestal and a laser receiver on the other, precise aerosol backscatter as a function of altitude will be determined by parallax; that is, by "walking up" the argon laser beam with the laser receiver. From a knowledge of the angle scattering function of aerosols, the concentration with altitude can be determined. Reflection from the satellite plus a knowledge of the satellite range and reflection characteristic allow total atmosphere attenuation of 0.4880 μ to be determined.

With a Q-switched ruby laser and KDP generation of second harmonic, aerosol size distribution will be indicated by observing backscatter from the laser beam as a function wavelength. Reflection from the satellite will characterize total atmospheric transmission at 6943 Å and 3472 Å.

A sophisticated experiment involves the determination of absolute humidity versus altitude techniques. The beam from a nitrogen temperature Q-switched ruby laser is directed into a Raman cell containing $C^{12}S_2^{32}$ and $C^{12}S_2^{34}$, isotopes of carbon disulfide. Raman shifted outputs from the cell lie at 7256.3 Å and 7241.8 Å. One Raman line is in a water vapor absorption line and the second outside of the line. The selective extinction by the water vapor line as determined by aerosol scattered return signals will characterize the altitude distribution of water vapor. Selective extinction in returns from the satellite indicates total water vapor content in the atmosphere.

The variations of cw laser reflection from the Explorer 22 satellite will depend upon the interference pattern due to the corner cube array, upon velocity aberration effects, and upon atmospheric turbulence. Clearly, to evaluate this fluctuating intensity function is complex, but use of a cw laser plus geometrical separation of transmitter and receiver offer potential for unraveling these effects.

Laser-aided acquisition will utilize the same scanning of a 1.2-mrad field-of-view optical tracker over the 3-mrad tape coordinate uncertainty as sunlit twilit acquisition utilizes. However, the argon laser will be radiating a 3-mrad beam into the uncertainty interval, so sunlight is not required. Narrowing the laser beam after acquisition would permit more accurate error signals. Success of this method will allow experimental use of nontwilight Explorer 22 passes.

Laser-aided tracking will direct the argon laser beam at a sunlit satellite already being followed by the optical tracker. Increased received signal strength should result. The optical receiver will then be filtered to pass only argon laser radiation. Success of this method should permit tighter error signals and tighter tracking.

Experiments with pulsed laser satellite ranging will also be attempted. It is not expected that ranging results will be significantly different from those already obtained by other groups.

The Explorer 22 program provides the basic equipment for both the atmospheric and Gemini 7 experiments; namely, the dual pedestal Nike system with independent and slaved pedestal capability, the 40.64-cm (16-in.) optical receivers (Fig. 3) with provisions for various filters and detectors, and the argon laser. Equipment used for the Explorer 22 work alone includes the punched tape acquisition system and the automatic optical tracker.

The additional piece of equipment required for atmospheric and navigational experiments is the pulsed laser system. Figure 4 shows details of the laser head design that provides for 1.524 by 15.24-cm (0.6 by 6-in.) ruby or neodymium glass laser rods in a closed coupled cavity. The laser rod temperature may be controlled over the range from 273° K to 357° K to an accuracy of ± 1°. The laser will have a capability of more than 1 joule per Q-switched pulse at 10 pulses per minute.

The laser power supply and closed cycle cooling system will be located adjacent to the Nike pedestal with the laser remotely controlled from the tracking station. The Q-spoiled laser is collimated by a 30.48-cm (12-in.) Newtonian reflector, with beam divergency adjustable over the range of 0.5 to 10 mrad. Provisions have been made for a continuous pulse output sampling by means of a high-speed photodiode. Between the laser head and the collimating telescope, provision is made for either a Raman cell or a frequency doubling KDP crystal.

A system used only with the pulsed laser is the satellite ranging system, shown in Figure 5. As indicated, a high-speed photodiode pulse activates a

10-nsec range counter and is also displayed on a dual beam oscilloscope. A range prediction derived from the pulsed tape acquisition aid system is presented as delayed sweep trigger for the second scope trace, the delay being the range prediction minus an adjustment based on confidence in the prediction. When the scope is triggered, it sweeps typically at a rate of 10 nsec/cm. This displays the interval of time expected for the return pulse in high linear resolution. When the pulse is received, it displaces the time base and is recorded by a scope camera. The pulse also stops the range counter at the measured range value.

Following the Gemini 7 mission, the modified Nike system will be retrofitted with the pulsed laser, the optical tracker, and the acquisition aid. The equipment will be established at a site near Ames Research Center at Moffett Field, California. Explorer 22 tracking and atmospheric propagation experiments will commence at that time. The experimental program is flexible, and modifications to the plans of this paper are possible as the field program proceeds.

The Gemini 7 Optical Communications Program is significantly influenced by the Gemini spacecraft orbital characteristics. The Manned Spaceflight ground stations have the long range acquisition and tracking capability necessary for narrow beamwidth optical communications. It follows that stations of the Manned Spaceflight Network are the most desirable sites for conducting this experiment. The best orbital coverage readily available is thus from the Manned Spaceflight Network station in Hawaii (22° N). The crux of the NASA-Ames Research Center efforts on Gemini 7 Optical Communications is thus the adaptation of the Explorer 22 equipment for such use, and its installation at Kauai Island, Hawaii.

Stations of the Manned Spaceflight Network are logical choices as sites for the Laser Communication experiment. The optical ground station operated by MSC is located at White Sands, New Mexico. After evaluating a number of site selection criteria, the optical ground station operated by ARC was located on Kauai, Hawaii, consideration having been given to Guaymas, Mexico; Carnarvon, Australia; and Western Test Range, California. The criteria used in the selection were cloud cover, atmospheric turbulence, latitude, viewing angles, accessibility, acquisition aids, logistics, sky illumination, and available facilities.

Minimum probability of cloud cover is obviously important. Meteorological data from all sites were examined for the year preceding the mission schedule. One must note that data collected from weather stations several miles distant from the proposed site may have no relation to the weather at the site. For instance, the proposed site at Western Test Range lay directly on the coast and was subject to periodic heavy coastal fog, while the inland weather station at

WTR would report clear skies. The reverse situation was true of Kauai, Hawaii, where the weather on the northeast coast is intensely rainy, while the southwestern coast at the tracking station is much drier.

Atmospheric turbulence causes fluctuations and beam direction changes that can degrade optical communications to and from space. Atmospheric turbulence effects decrease with altitude. Thus, a high-altitude Manned Spaceflight Network station becomes a desirable site. Hawaii [1154 m (3787 ft)] and White Sands [1234 m (4048 ft)] are the highest Manned Spaceflight Network stations in this hemisphere.

The latitude of the optical ground station determines the number and angular altitude of satellite passes. The number of passes with angular altitude above 40° for the various sites studied were:

Carnarvon, Australia	19
Hawaii	15
Western Test Range	11

for originally planned 72° Gemini 7 launch. Current plans for zero-orbital inclination favor a mid-latitude site such as Hawaii over sites at extreme latitudes such as Carnarvon and Western Test Range, California.

All Manned Spaceflight Network stations have suitable viewing angles with no major local obstructions. Accessibility of all these stations is guaranteed to be adequate. All stations have acquisition aids. However, the stations do not all have the FPS-16 radars necessary for optimum tracking of the spacecraft and pointing of the laser beam. Hawaii, Western Test Range, and White Sands have such radars, but Carnarvon and Guaymas do not.

Logistics was the final major difference between network stations, with sky illuminance and available support facilities adequate at all stations. Essentially, the final decision became that the FPS-16 radar availability at low latitude in Hawaii overcame the moderate to poor logistics situation.

Location of the Laser Communication ground station at a major spacecraft tracking station permits full use to be made of the acquisition and tracking capabilities of the station. As the spacecraft comes over the local horizon, TELTRACK or AGAVE telemetry tracking antennas acquire the spacecraft 225-to-260-MHz telemetry transmission. These antennas are pre-positioned by

computer from NASA-Goddard. Once acquisition has been accomplished, the C-band FPS-16 antennas are slaved to the telemetry tracking antennas and acquire the spacecraft, aided by the on-board C-band radar beacon transponder. The FPS-16 tracks the spacecraft from a few degrees above the horizon with an accuracy of tenths of a milliradian.

The laser communication receiving equipment, which is mounted on modified Nike-Ajax tracking pedestals, is slaved to the FPS-16 with an overall tracking accuracy of 0.2 to 0.4 mrad. Slaving to the FPS-16 is accomplished by taking 1 and 16-speed synchro position information from the FPS-16 and comparing it with synchro position data from the Nike-Ajax system. An error signal proportional to the difference between the angles of the two systems is generated and fed to the Nike pedestals, which then null the pointing error.

Figure 6 is a block diagram of the FPS-16 slaving system. FPS-16 servos operate at 60 Hz while those of the Nike system are 400 Hz. This has necessitated installation of 60-Hz synchros in the Nike-to-FPS-16 slaving loop.

The basic communication experiment involves the experimental transmission of voice intelligence by a hand-held pulsed FM gallium arsenide laser transmitter from the Gemini spacecraft to the ground receiving station. The factors to be evaluated will be the characteristics of the pulse following propagation through the atmosphere, the received signal strength versus time, amplitude fluctuations due to pointing errors or atmospheric effects, and the quality of the demodulated audio voice intelligence.

For this experiment, two optical receivers are being utilized, partially for backup security, and partly for monitoring the magnitude of astronaut pointing errors. Acquisition and recording are illustrated in Figure 7.

As indicated, two channels of received information are being displayed on a dual beam oscilloscope equipped with a high-speed motion picture camera. Correlation of the received signals, their pulse shape and amplitude, is then possible. Both signal channels are then amplitude and frequency-demodulated. The output of the frequency-demodulated channels is the audio intelligence transmitted by the astronauts. The output of the amplitude-demodulated channels will contain amplitude modulation on the signal due to both pointing errors and atmospheric effects. Spectrum analysis of both the amplitude modulation and audio channels will be possible after the mission. Additional data to be recorded include time, capsule communication, azimuth, elevation, and range information. During experimental orbits, the naval base at Barking Sands will probe the atmosphere to 50 km with weather balloons and from 50 to 200 km with Arcas

meteorological rockets. Weather prediction for forthcoming orbits will be available from the weather bureau in Honolulu.

The two tracking pedestals of the Nike system are slaved together, and each is equipped with an optical receiver and signal processing electronics. By placing the receivers some 122 m (400 ft) apart, it will be possible by time correlation of the received intensity from the two receivers to obtain quantitative data on the pointing ability of the astronaut. This experiment is limited by the fact that the maximum separation of the pedestals, 152 cm (500 ft), is of a small fraction of the minimum laser spot size of the earth, ≈610 cm (≈2000 ft). It is obvious, however, that nothing may be deduced from a single receiver other than that the astronaut is either on or off the target.

The experimental equipment, shown in Figure 8, consists of the two Nike-Ajax tracking pedestals and the tracking van. Each pedestal is equipped with a 40.64-cm (16-in.) Newtonian telescope of 314.4-cm (60-in.) focal length. A 100-Å bandpass filter centered at 9060 Å is located within a collimating lens system.

The optical beacon used by the astronaut to acquire the receiver site is an argon laser of 3-W cw output power. A commercial model of this laser system, consisting of the laser head, power supply, and closed-cycle liquid cooling system, is shown in Figure 9. An identical laser head will be used on the Gemini program. However, the power supply and cooling unit have been integrated into a mobile field cart that has environmental protection. An optical chopper is provided that interrupts the laser beam at 7 Hz or permits cw operation, depending on whether the injection laser radiation is being received or not.

The ARC Laser Communication equipment is currently in final stages of assembly. This equipment will be air-lifted to the NASA-Kokee Park Tracking Station on Kauai, Hawaii. A site is being prepared along the FPS-16 boresight range. This station will participate in the Gemini 7 pre-flight simulation tests of beacon visibility and of receiver operation with a gallium arsenide laser transmitter. In December, the equipment will be used in support of the Gemini 7 (MSC-4) Optical Communications experiment. Following this mission the equipment will be moved to San Francisco Bay area, where the Explorer 22 program of atmospheric propagation and satellite navigation and tracking experiments will be conducted.

It is anticipated that the results of the MSC-4 experiment to be conducted on Gemini 7 will have a profound effect upon the future of space optical communications. The success of this experiment is bound to stir the imagination

of program planners. Future effects in deep-space optical communication will be able to proceed with enhanced definition and surety.

Demonstration of acquisition and tracking of the ground station by the astronauts will exhibit the ability of manned spacecraft systems to meet critical performance requirements without requiring heavy costly automatic tracking techniques in the space communications transmitter.

Examination of the propagation data obtained during the MSC-4 experiments and also the Explorer 22 experiments may result in the development of new modulation/demodulation techniques to circumvent the degrading effects of the atmosphere on optical communications. The experience gained on the programs will aid materially in the selection and development of suitable sites of site selection for future NASA optical ground stations. Further, space techniques will have been developed to obtain valuable atmospheric data:

aerosol backscatter and attenuation versus range

aerosol size distribution versus range

humidity and total water vapor versus range.

In addition, laser-aided acquisition and tracking of satellites will open the door to future high-resolution radar systems for satellite tracking.

The versatility of the available equipment and techniques allows many new experiments relating to optical technology that extend beyond the present efforts to be conducted. Table III lists some possible experiments of this type that could be economically performed with future Gemini/Apollo spacecraft and with modestly improved ground facilities. Such experiments could be very useful in extending space optical technology, soon and simply, before OTAES and deep-space special spacecraft are available.

The earliest returned signals from a satellite were detected by Dr. H. Plotkin and his associates at NASA-GSFC. The present ARC program profits from the experience and advice of Dr. Plotkin and his associates. It is anticipated that the results will provide the scientific laser community with valuable atmospheric propagation data, largely as a result of this cooperation.

Success on the MSC-4 Optical Communications experiment depends heavily upon the efforts of Mr. W. L. Thompson and his associates, who have planned and implemented the basic communication experiment at NASA-MSC. By adding

some additional studies to this experiment, this program should serve as an effort of significance to future system designs.

Appendix

An argon laser plus field support service were provided to NASA Manned Spacecraft Center by EOS for the Gemini 5 Laser Beacon Experiment in August 1965. This appendix reports the results obtained during these tests, conducted at the White Sands Missile Range. Included are data on the argon laser used and comments on the operational problems encountered.

Scope of Effort. The argon laser was mounted on a platform oriented by a modified Nike-Ajax tracking system. The Nike-Ajax system was, in turn, slaved to an FPS-16 instrumentation radar, capable of both beacon track and skin track of the Gemini spacecraft.*

The major design requirements of the argon gas laser were as follows:

power output - 1 W

beamwidth - 1 to 2 mrad

modulation frequency - 3 to 10 pulses/s (adjustable).

The laser was capable of being boresighted to the Nike-Ajax platform to an accuracy of the order of 0.3 mrad. The laser beacon included all power supplies, cooling systems, and instrumentation necessary for operation.

Results. The argon laser beacon was fabricated, tested, and installed on the Nike-Ajax platform prior to the GT-5 launch. The laser beacon met or exceeded all operating specifications and was operational throughout the GT-5 experiment.

The astronauts were unable to acquire the beacon on three separate orbits. Several adverse factors contributed to this inability. An understanding of these

* The FPS-16 can track the Gemini 5 C-band beacon within ±0.1 mrad. Static tests with the Nike-Ajax system indicated that it could be slaved to the FPS-16 radar to within ±0.3 mrad.

factors can improve the likelihood of success on forthcoming experiments involving an argon laser beacon.

Laser Operational Data. A silicon photovoltaic cell was mounted on the rear of the laser and calibrated so as to indicate the output from the beacon. During the orbits when the experiment was attempted, the laser was operated between 0.9 and 1.1 W. The laser output was chopped at approximately 5 to 6 pulses per second during the experimental operation. The output was approximately a square wave. Signals corresponding to the chopper frequency and the laser output power were fed to a recorder in the NASA van for future reference.

The laser's angular beamwidth was measured by observing the diameter of the illuminated area on the boresight target 442 m (1450 ft) from the laser. The beamwidth was found to be 1.5 mrad. Boresight of the argon laser with the Nike-Ajax platform was accomplished by setting up a target on the face of a building at the FPS-16 boresight tower, taking into account the parallax resulting from the displacement of the boresight telescope from the laser beacon output. Boresight was accomplished to well within 0.3 mrad. The use of "Scotchlite" for the boresight target permitted checks of the boresight in daylight by observing the illuminated target through the boresight telescope.

Attempted Experiments. The only orbits available at White Sands Missile Range were daylight passes, the earliest being about 6:00 am, 1/2 hour after sunrise. On the average, two good passes would occur per day having elevation angles above 40° and slant ranges of about 161 km (100 mi).

The astronauts were instructed to attempt to see the laser on August 27, 1965, orbit 92, and on August 28, 1965, orbits 105 and 197. They did not succeed in acquiring the laser during any of these tries.

A number of factors reduced the astronauts' ability to acquire the laser:

1. The spacecraft attitude control system had malfunctioned and the astronauts were not allowed to stabilize the spacecraft to look down into the vicinity of the laser site.

2. The astronauts were unfamiliar with the terrain and the location of the site and, because of the way in which instructions were given, were probably looking at the White Sands Dry Lake rather than the site, 129 km (80 mi) to the south.

3. The astronauts did not have any nighttime passes in which acquisition of the laser would have been very easy. [The laser looks like a -7 magnitude star to an observer 161 km (100 mi) distant.]

4. The astronauts did not have optical filters, which would have improved the contrast of the laser with respect to the background. [The irradiance of the laser at 161 km (100 mi) is equivalent to that received from the sunlit earth in a 10^{-7} steradian field of view.]

It was found that RFI, generated during operation of the argon laser, was sufficient to interfere with the acquisition mode of the FPS-16 radar. Because the FPS-16 tracked satisfactorily, once acquisition had taken place, an operating procedure was adopted where the laser would remain off until the FPS-16 operator indicated they were properly tracking.

Summary. Perhaps the most important benefits from the effort described above are those things that will contribute to the success of related programs in the future. The understanding of the factors that contributed to the failure of the astronauts to observe the beacon are most important in this respect. Further, the planning of improved procedures for the Gemini 7 mission, plus the design improvements being incorporated in an advanced laser beacon, will help insure a minimum of difficulties in the future.

TABLE I. ATMOSPHERIC EXPERIMENTS

A. EXPERIMENTS TO BE ACCOMPLISHED

EXPERIMENT	LASER	WAVELENGTH	POWER	AEROSOL RANGE BY	PRINCIPAL DATA
cw Backscatter & Attenuation	cw Argon^{+}	4880 Å	1-2 W cw	Parallax	Precise aerosol backscatter, precise attenuation to and from satellite
Pulsed Backscatter & Attenuation	Q-Switched Ruby + Doubler KDP	6943 Å +3472 Å	100 MW +10 MW	Time Delay	Aerosol size distribution, attenuation vs wavelength, satellite range

B. EXPERIMENTS TO BE ATTEMPTED

EXPERIMENT	LASER	WAVELENGTH	POWER	AEROSOL RANGE BY	PRINCIPAL DATA
Humidity Experiment	Raman-Shifted Ruby:			Time Delay	Absolute humidity vs altitude, total water vapor in atmosphere
	$C^{12}S_2^{32}$	7252.3 Å	5-10 MW		
	$C^{12}S_2^{34}$	7241.8 Å	5-10 MW		

TABLE I. ATMOSPHERIC EXPERIMENTS (Cont'd)

C. ALTERNATIVE EXPERIMENTS

EXPERIMENT	LASER	WAVELENGTH	PURPOSE
cw Backscatter & Attenuation	cw Argon$^+$	5145 Å 5682 Å	Alternatives to 4880 Å for precise aerosol backscatter and attenuation measurements
Pulsed Backscatter & Attenuation	Q-Switched Nd:Class + Doubler KDP	1.06 μ 0.53 μ	Alternative to ruby + KDP as PLIDAR for aerosol size distribution and attenuation versus wavelength
Atmospheric Constituent Experiment	Ruby or Nd:Glass + Various Raman Shifters	Assorted	Determination of absorption at wavelengths characteristic of CO_2, O_2, and O_3

TABLE II. NAVIGATION AND TRACKING EXPERIMENTS

A. EXPERIMENTS TO BE ACCOMPLISHED

EXPERIMENT	LASER	WAVELENGTH	POWER	PRINCIPAL DATA	METHOD
cw Laser Reflection Experiment	cw Argon$^+$	4880 Å	1-2 W cw	Velocity aberration, lobe pattern from cube corner array, amplitude scintillation vs rf and optical Doppler frequency shift	Calculated curves will be compared with experimental values for differing spacings between transmitter and receiver

B. EXPERIMENTS TO BE ATTEMPTED

EXPERIMENT	LASER	PRINCIPAL DATA	METHOD
Laser Aided Acquisition	cw Argon$^+$	Difficulty of automatic acquisition (probability of acquiring vs system parameters)	Use both manual and programmed pointing; use scan or beam divergence mode; try both visual and automatic star tracker acquisition.
Laser Aided Tracking	cw Argon$^+$	Satellite azimuth and elevation angles vs time; laser pointing error vs time	Measure the platform position vs time; correct with star tracker error signal vs time.

TABLE II. NAVIGATION AND TRACKING EXPERIMENTS (Cont'd)

C. ALTERNATIVE EXPERIMENTS

EXPERIMENT	LASER	PRINCIPAL DATA	METHOD
Laser Range Determination	Q-Switched Ruby	Range vs time	Measure two-way transit time.

TABLE III. POSSIBLE ADDITIONAL EXPERIMENTS

REQUIRED FACILITIES

EXPERIMENT	STATION 1 (GROUND)	STATION 2	NOTES
0.1 arc-second tracking of a ground beacon	Present ground station	Balloon-borne optical tracker	High-altitude aircraft could also be used. Low-orbit satellites possible although tracking rates are excessive.
Tracking in presence of spacecraft motion	As above	As above using shake fixtures to induce additional disturbances	As above
Space-to-ground-to-space loop closure	As above	Balloon-borne optical station	High-altitude aircraft could also be used.
Point ahead experiment	As above	Laser transmitter with point ahead capability located at remote [161-km (100-mi)] ground station	Airborne or spaceborne stations could be employed although unnecessary.
Transfer tracking from one ground station to another	Present ground station plus additional receiver	Laser transmitter with tracking transfer capability located at remote [161-km (100-mile)] ground station	----

TABLE III. POSSIBLE ADDITIONAL EXPERIMENTS (Cont'd)

REQUIRED FACILITIES

EXPERIMENT	STATION 1 (GROUND)	STATION 2	NOTES
Optical heterodyne detection on earth	Present ground station with receiver modified for heterodyne detection	Modulated transmitter balloon-borne	Initial experiments might be carried out between remote ground stations.
Communication with 10-MHz bandwidth	As above	As above	Ordinary receiver could be used for comparison to optical heterodyning.
Atmospheric effects	Present ground station	Wide-beam laser transmitter carried on board low-altitude satellite	Scintillation and polarization effects can be evaluated.

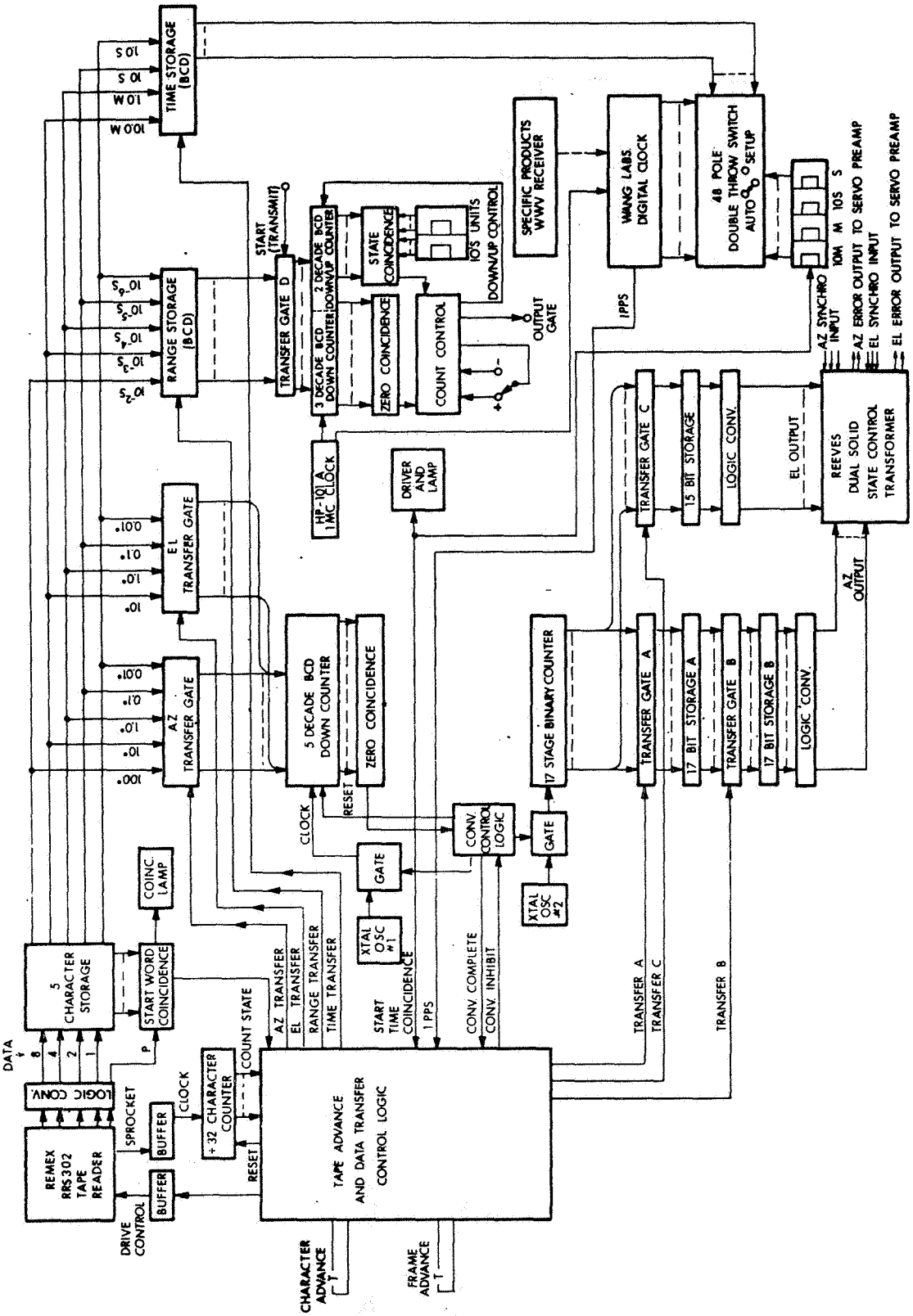

FIGURE 1. ACQUISITION AID SYSTEM

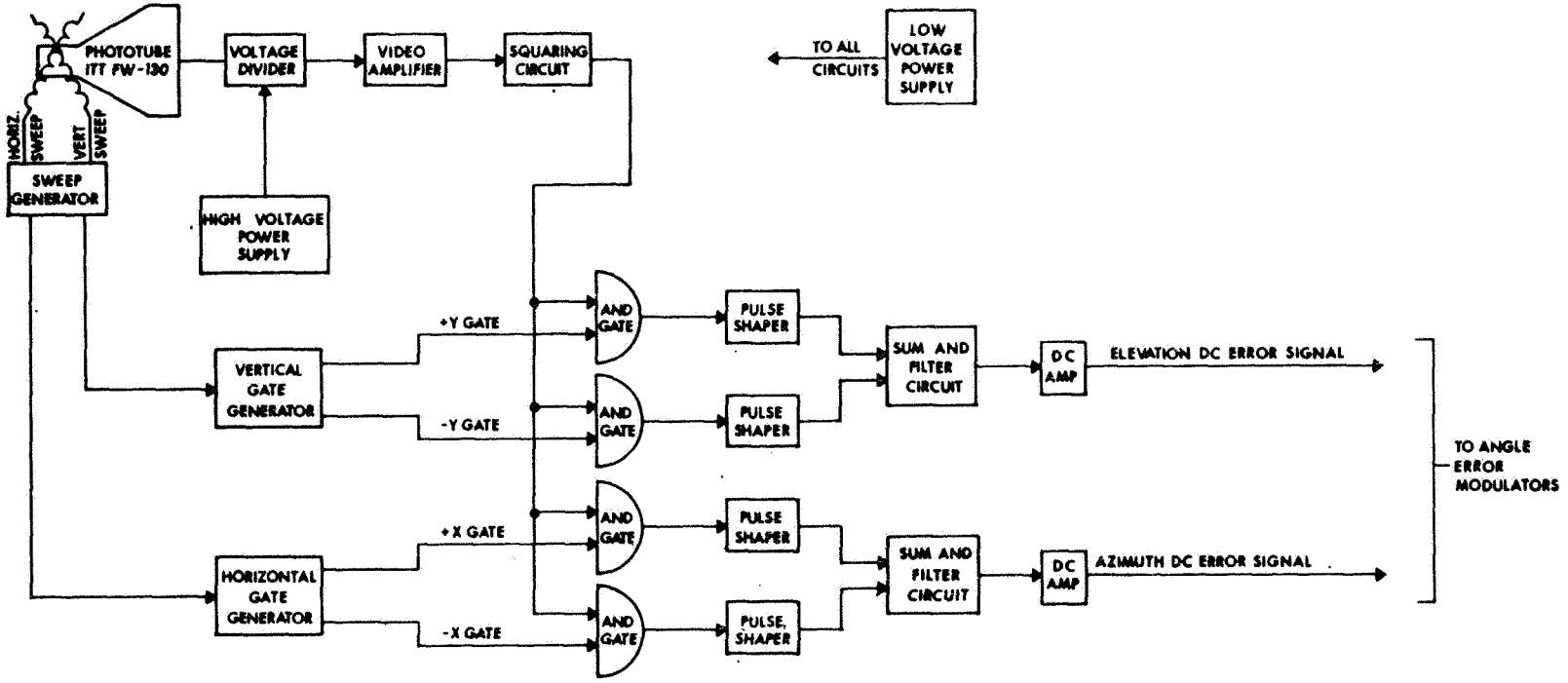

FIGURE 2. OPTICAL TRACKER

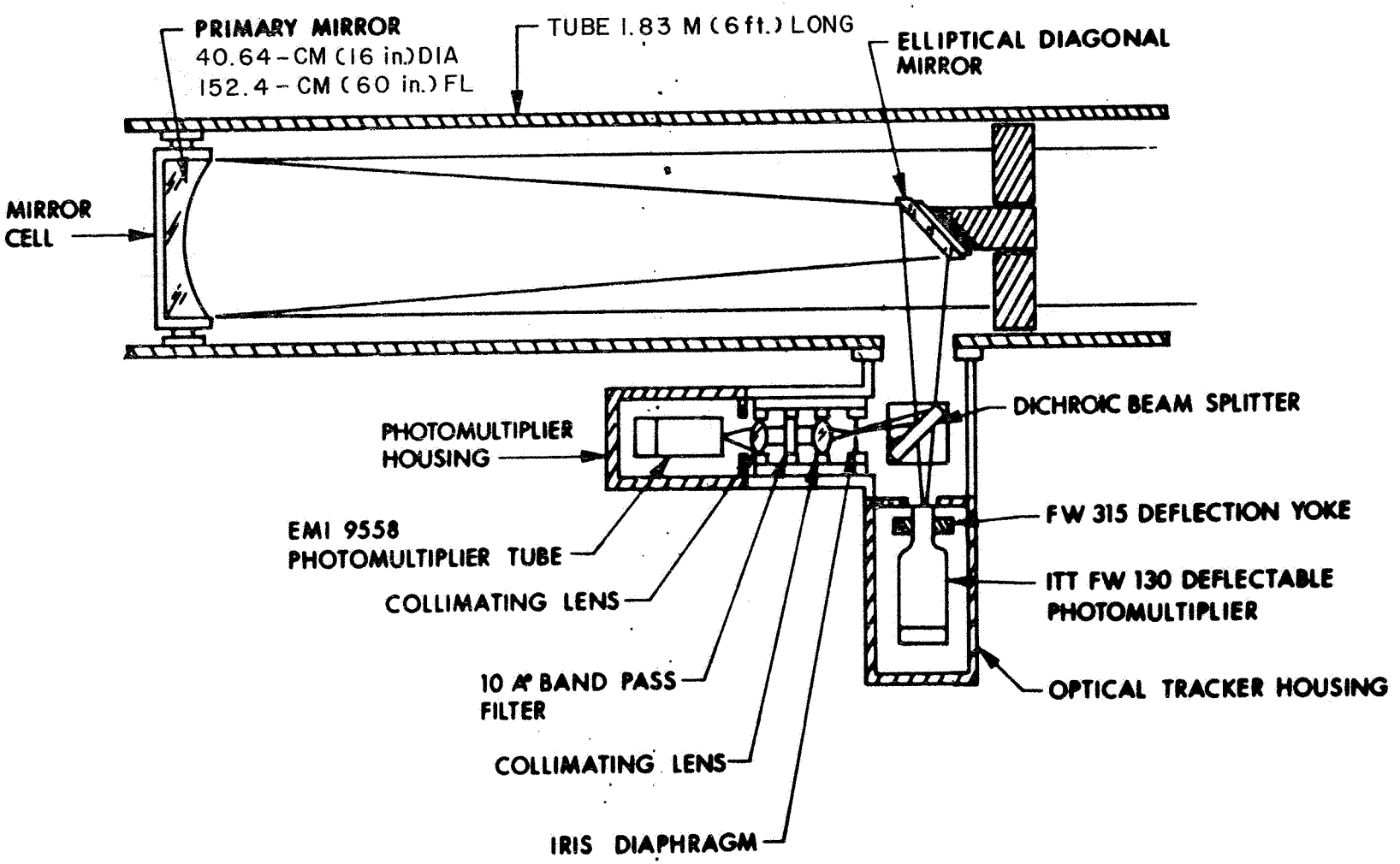

FIGURE 3. 40.64-CM (16-in.) OPTICAL RECEIVER

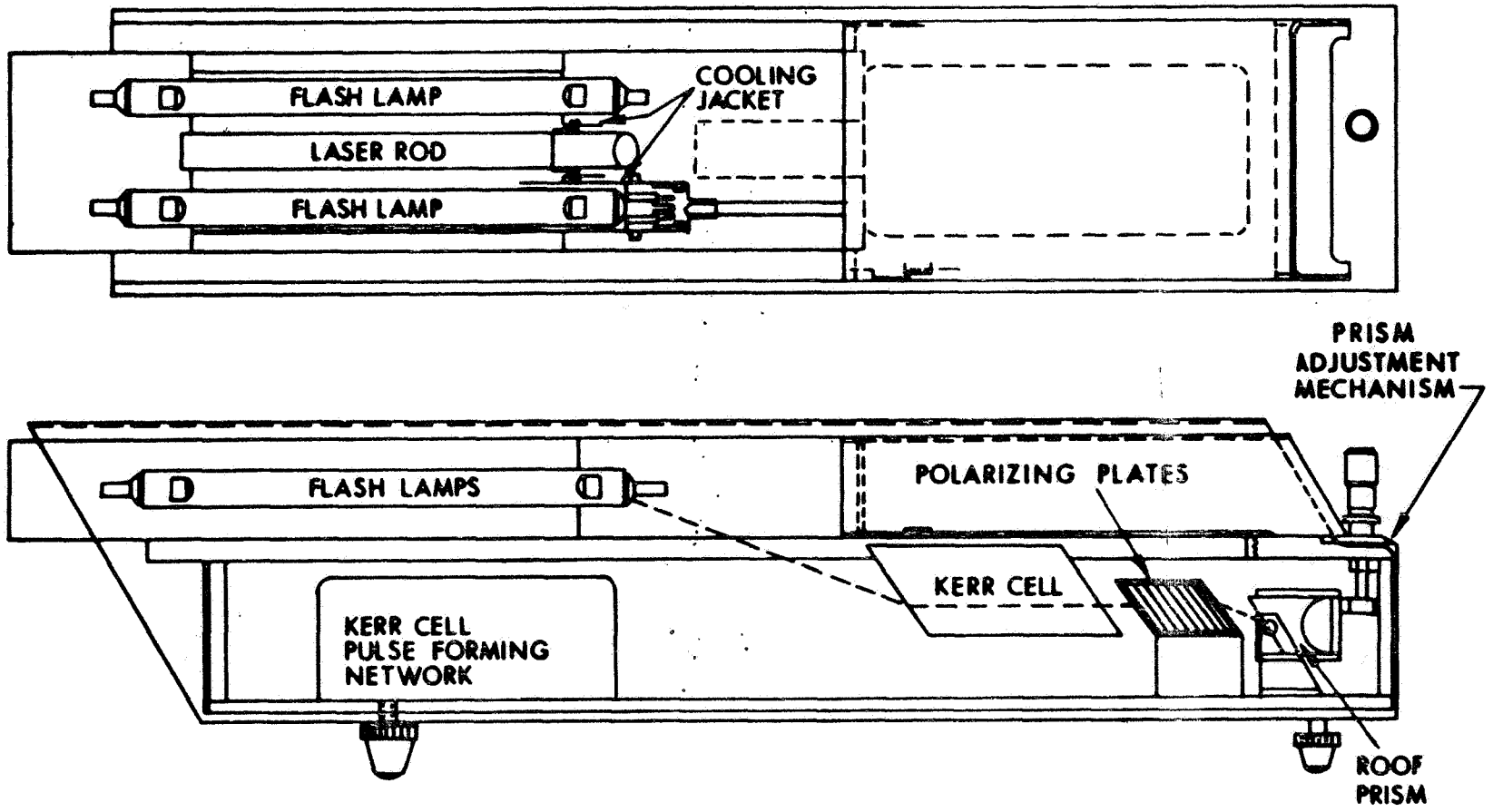

FIGURE 4. Q-SWITCHED LASER

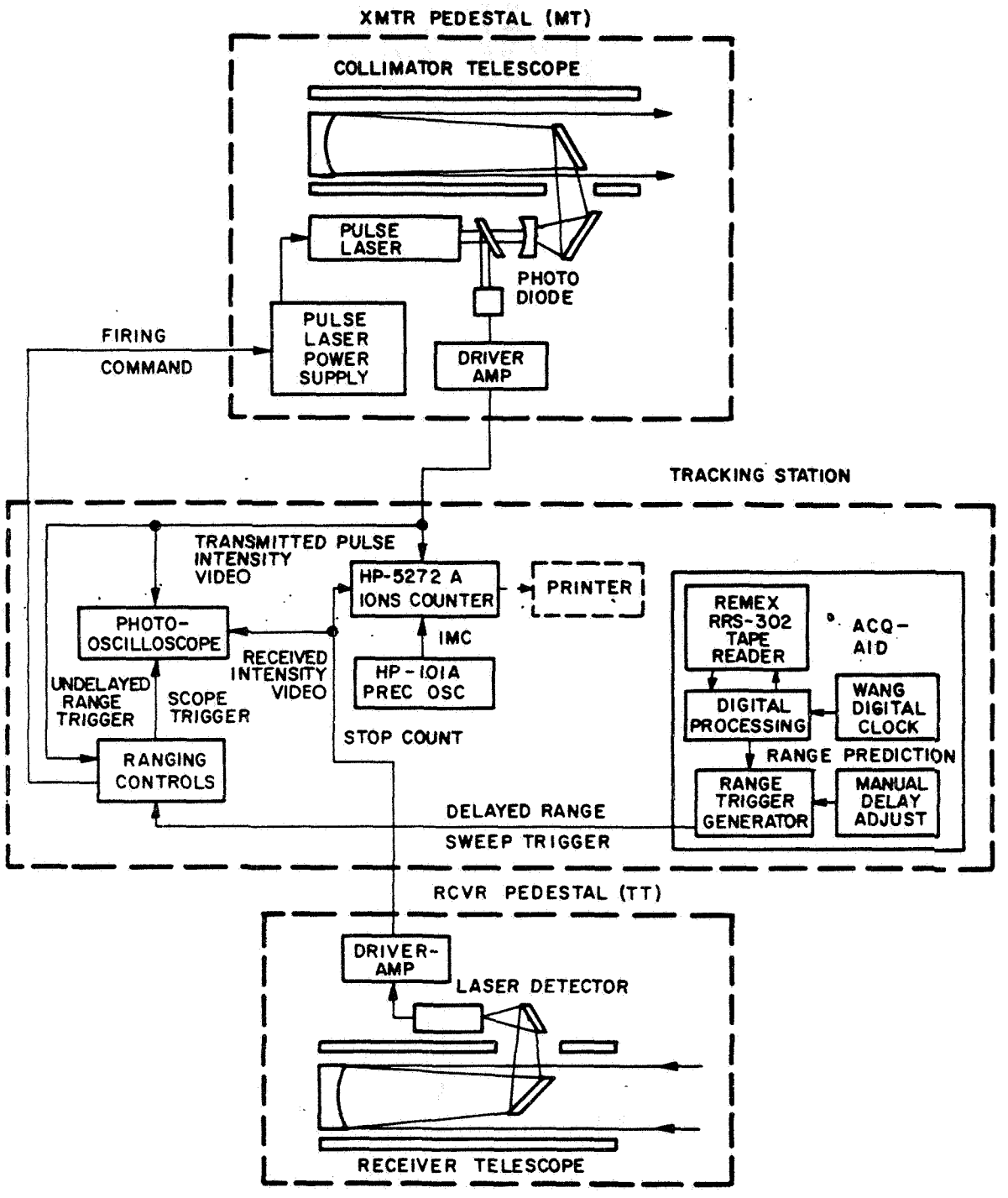

FIGURE 5. SATELLITE RANGING SYSTEM

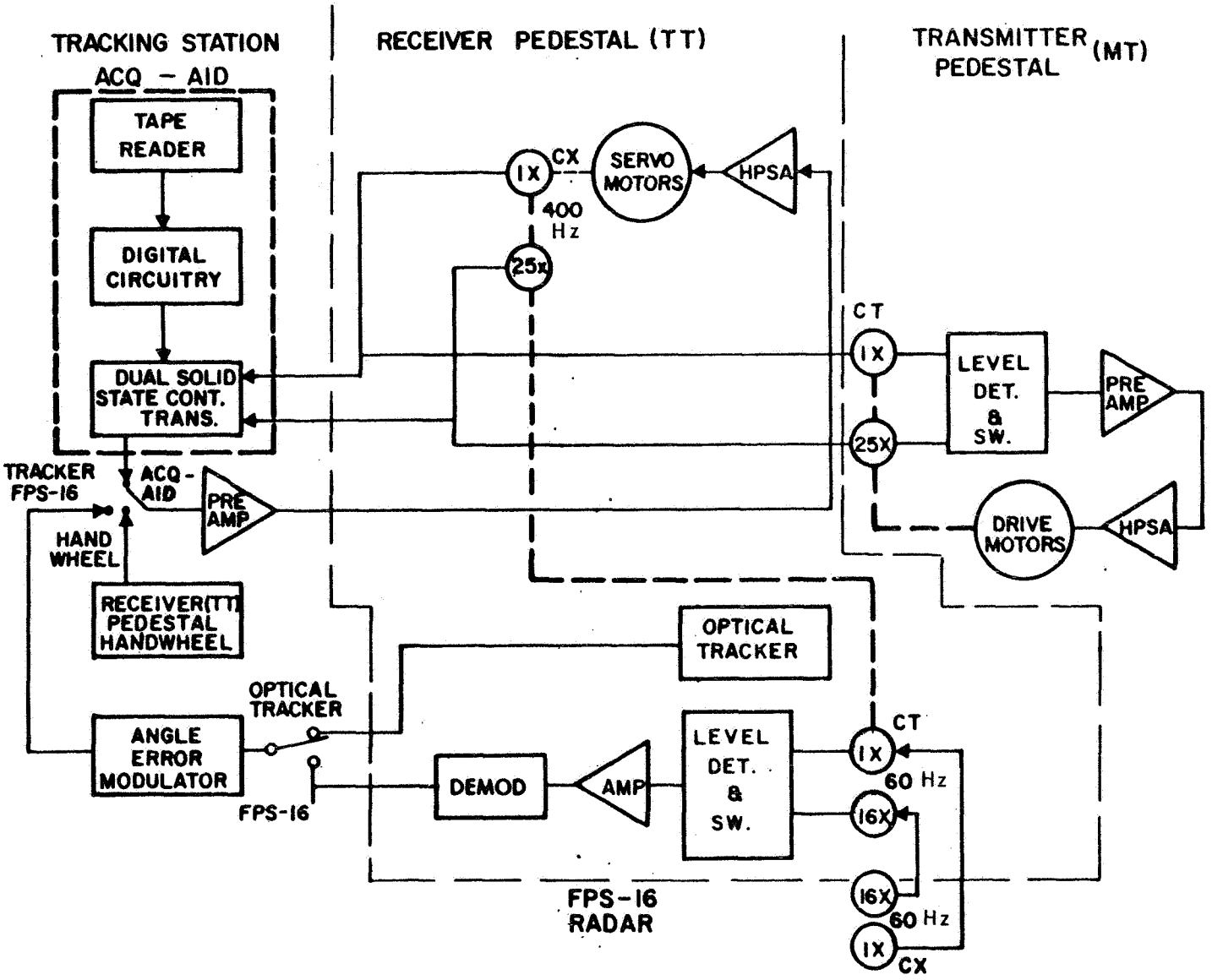

FIGURE 6. FPS-16 SLAVING SYSTEM

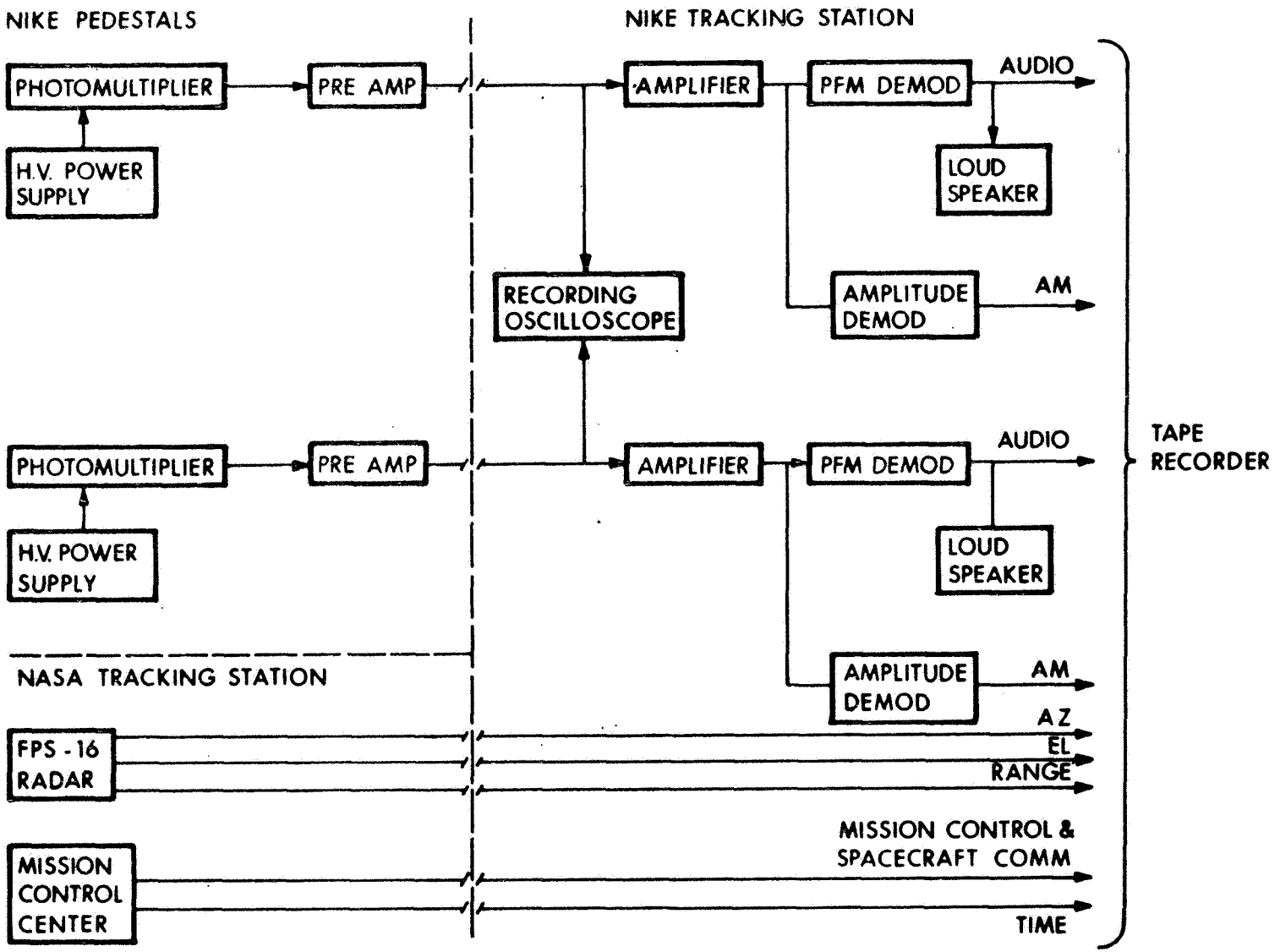

FIGURE 7. DATA SYSTEM

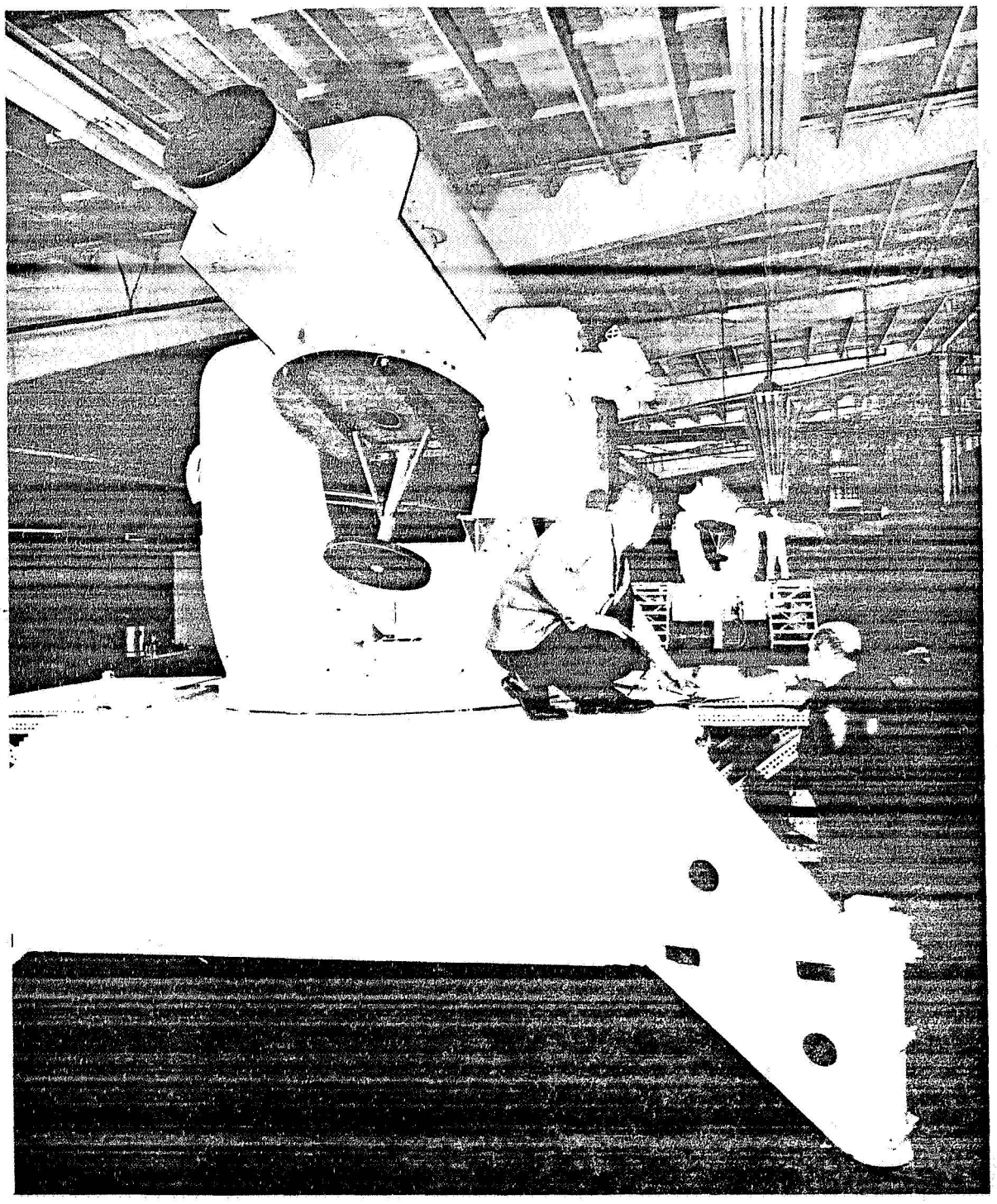

FIGURE 8. EXPERIMENTAL EQUIPMENT

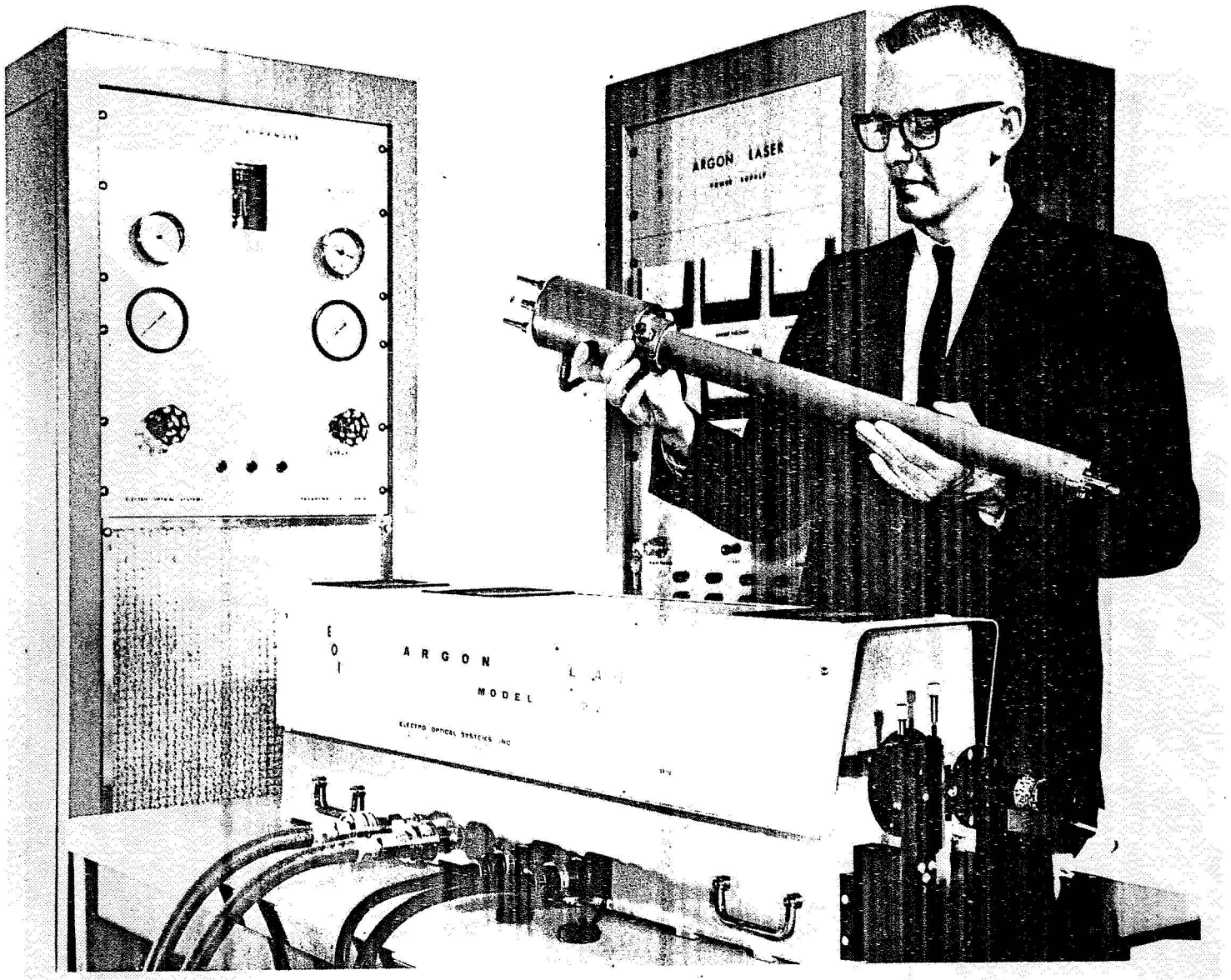

FIGURE 9. ARGON LASER